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(54) Title: METHODS AND APPARATUSES TO PROVIDE A BROADBAND LIGHT SOURCE WITH TWO OR MORE OUTPUT PORTS

(57) Abstract: Various methods, apparatuses, and systems are described in which a broadband light source supplies multiple sources of light. The broadband light source may have multiple gain stages including a common gain stage connected to a first output gain stage and a second output gain stage. The common gain stage may generate and propagate bi-directionally ASE light having a first band of wavelengths. The common gain stage may supply the ASE light to both the first output gain stage and the second output gain stage. The second output gain stage may generate ASE light in a second band of wavelengths by using the ASE light in the first band of wavelengths as a pumping light.

METHODS AND APPARATUSES TO PROVIDE A BROADBAND LIGHT SOURCE WITH TWO OR MORE OUTPUT PORTS

RELATED APPLICATIONS

[001] This application claims the benefit of Korean Patent Application entitled "Broadband Light Source," Serial No. 2002-71372, filed November 16, 2002.

FIELD

[002] This invention generally relates to a broadband light source. More particularly an aspect of this invention relates to a broadband light source with two or more output ports.

BACKGROUND

[003] A low power broadband light source having a single output port has been widely used for optical measurement and optical sensing since it possess a wide operating wavelength range and low coherence. Some high power broadband light sources have been used in optical communication systems.

[004] Broadband light sources can be used to measure operational characteristics of an optical element based on the wavelength of the optical element such as in an optical spectrum analyzer. When measuring the characteristics of optical elements, operating with a broadband wavelength range at a high optical power reduces measurement errors but increases costs. Two or more high power broadband light source may be used to supply a high power broadband light source for each wavelength range of broadband light applied to the optical measurement device.

[005] Broadband light sources may also be used as a light source for fiber optic networks using a wavelength-division-multiplexing passive optical network. A wavelength-division-multiplexing fiber optic network typically uses two high power broadband light sources in order to assign a band of upstream signals and a band of downstream signals.

[006] Typically, bi-directional transmission of the upstream and downstream signals exists between the central office and the subscribers. The two independent broadband light sources in the wavelength-division-multiplexing fiber optic network typically supply light in the different bands of wavelengths such as the C-band (1530

nanometers (nm) ~ 1560 nm) and L-band (1570 nm ~ 1600 nm). Each broadband light source operates in different band of wavelengths. Each independent broadband light source uses two or more gain stages as well as the optical components in that gain stage such as pump lasers to support each of those gain stages. However, using multiple discrete broadband light sources increases system cost and the physical space occupied by the light system.

[007] Some broadband light sources that are based on the semiconductor technologies such as light-emitting diodes and super luminescent diodes may be small and compact. However, it is not easy to increase the output power of light supplied from that source due to the coupling loss to the fiber and the potential lasing of a narrowband signal induced by the reflection of the broadband signal in the broadband light source. An alternative solution to semiconductor technologies is amplified spontaneous emission (ASE) light from a pumped Erbium doped optical fiber. Some broadband light sources using an Erbium doped optical fiber amplifier with a single output port that supply a single band of wavelengths have been used.

[008] Figure 1 is a block diagram of a prior art broadband light source using an Erbium-doped optical fiber. Erbium doped optical fiber 103 emits ASE of C-band. A pump light 109 using wavelength-division-multiplexer 104 supplies light to the Erbium-doped optical fiber 103. The Erbium-doped optical fiber 103 generates ASE light and transmits the light bi-directionally 107, 108. The single port broadband light source has a disadvantage of not using ASE light that progresses in the opposite direction of the optical output port 110. For this, the single port broadband light source maximizes optical power at the optical output port 110 by reflecting the light using the optical reflector 101. The second wavelength-division-multiplexer 102 and the optical absorber 106 may be used to block the reflection of pumping light. This prior technology supplies one high power light containing a band of wavelengths per broadband light source. Thus, if two high power broadband light sources of the same band or high power light sources of two different bands are required, then the two high power broadband lights may be produced independently.

SUMMARY

[009] Various methods, apparatuses, and systems are described in which a broadband light source supplies multiple sources of light. The broadband light

source may have multiple gain stages including a common gain stage connected to a first output gain stage and a second output gain stage. The common gain stage may generate and propagate bi-directionally ASE light having a first band of wavelengths. The common gain stage may supply the ASE light to both the first output gain stage and the second output gain stage. The first output gain stage amplifies the ASE light from the common gain stage. The second output gain stage may generate ASE light in a second band of wavelengths by using the ASE light in the first band of wavelengths from the common gain stage as a pumping light.

[0010] Other features and advantages of the present invention will be apparent from the accompanying drawings and from the detailed description that follows below.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] Embodiments of the invention are illustrated by example and not by limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1 is a block diagram of a prior art broadband light source using an Erbium-doped optical fiber.

Figure 2 illustrates a block diagram of an embodiment of a single broadband light source with a common gain stage and two or more output gain stages.

Figure 3 illustrates a block diagram of an embodiment of a single broadband light source with a common gain stage simultaneously generating light in a first band of wavelengths and light in a second band of wavelengths.

Figure 4 illustrates an example optical power graph for each light signal of the bi-directional ASE generated from an embodiment of the common gain stage.

Figure 5 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the second gain stage that contained a gain flattening filter.

Figure 6 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the second gain stage that contains a Fabry-Parot filter and a gain flattening filter.

Figure 7 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the third gain stage.

Figure 8a illustrates a block diagram of an embodiment of the common gain stage that emits broadband light of a first portion of a first band of wavelengths to the second output gain stage and emits light of a second portion of the first band of wavelengths to the third gain stage.

Figure 8b illustrates a block diagram of an embodiment of the common gain stage that emits broadband light of a first portion of a first band of wavelengths to the second output gain stage and emits light of a second portion of the first band of wavelengths to the third gain stage.

DETAILED DISCUSSION

[0012] In general, various methods, apparatuses, and systems are described in which a broadband light source supplies multiple sources of light. The broadband light source may have multiple gain stages including a common gain stage connected to a first output gain stage and a second output gain stage. The common gain stage may generate and propagate bi-directionally ASE light having a first band of wavelengths. The common gain stage may supply the ASE light to both the first output gain stage and the second output gain stage. The first output gain stage amplifies the ASE light from the common gain stage. The second output gain stage may generate ASE light in a second band of wavelengths by using the ASE light in the first band of wavelengths from the common gain stage as a pumping light.

[0013] Figure 2 illustrates a block diagram of an embodiment of a single broadband light source with a common gain stage and two or more output ports. The broadband light source may have a common gain stage 206 and two or more output ports. A first output port 208 supplies light in a first band of wavelengths. A second output port 204 supplies a light in a second band of wavelengths. The first band of wavelengths is different than the second band of wavelengths. The broadband light source may have multiple gain stages 205, 206, 207. Note, the broadband light source could couple to N number of output gain stages, where each different output gain stage produces a light having a different band of wavelengths. Also, the multiple output gain stages may both supply the same band of wavelengths. Each different output port could supply a light having a different band

of wavelengths than the other output ports or some combination of different bands of wavelengths and common bands of wavelengths. However for simplicity, two output stages supplying light in different bands of wavelengths will be described.

[0014] The common gain stage 206 may have two ports 210, 211. The first port 210 of the common gain stage 206 connects to a first port 209 of a first output gain stage 205. The second port 211 of the common gain stage 206 connects to a first port 212 of a second output gain stage 207. The common gain stage 206 supplies Amplified Spontaneous Emission (ASE) light to both output gain stages 205, 207. In the common gain stage 206, the ASE light having a first band of wavelengths, such as the C-band, and a second band of wavelengths, such as the L-band, is generated and propagates bi-directionally. The optical power in the second band of wavelengths may be significantly lower in power or even negligible compared to the power in the first band of wavelengths. Arrows (201 ~ 204) show the bi-directional optical paths in the broadband light source. The C-band ASE light from the common gain stage 206 is amplified at the first output gain stage 205 and goes out through the first output port 208. The first output gain stage 205 acts as the booster amplifier for the wavelengths of light in the C-band. The first output port 208 supplies light in a first band of wavelengths such as the C-band to an optical measuring device, a wavelength-division-multiplexer passive-optical -network, or similar optical use.

[0015] The second output gain stage 207 generates ASE light having a second band of wavelengths, such as the L-band. The second output gain stage 207 may contain a physically longer Erbium-doped optical fiber than the Erbium-doped optical fibers used in the first output gain stage and the common gain stage. The physically longer Erbium-doped optical fiber may be used to generate ASE light in the second band of wavelengths. When light is optically pumped to an optical fiber with rare-earth-elements such as Er (Erbium), Pr (Praseodymium), and Yb (Ytterbium), ASE light is generated. In particular, in the case of doping with Erbium, ASE can be generated in the C-band and L-band based upon the physical length of the Erbium-doped optical fiber. ASE wavelengths in the C-band can be obtained in when optically pumping light having wavelengths of 980 nm or 1480 nm to Erbium-doped optical fiber. If the physical length of Erbium-doped optical fiber gets longer, wavelengths in the C-band operate as a pumping light to generate emission of wavelengths in the L-band.

[0016] The mixed L-band and C-band ASE light inputted from the common gain stage 206 is amplified in the front part of the Erbium-doped optical fiber (EDF) in the second output gain stage 207. The amplified C-band light propagates along the EDF generating L-band ASE light. The EDF in the second output gain stage 207 supplies high power L-band ASE light at the output of the EDF. The C-band ASE light from the common gain stage 206 acts as a secondary pumping light in the EDF in the second output gain stage 207. Thus, the second output gain stage 207 generates ASE light in the second band of wavelengths by using ASE light of the first band of wavelengths as a pumping light. A second output port 213 supplies high power broadband light in a second band of wavelengths such as the L-band. Thus, increasing the length in the second output gain stage EDF aids in converting the C-band light to L-band light and also increases the output power level of the light supplied to the second output port 213.

[0017] The common gain stage 206 may include an Erbium-doped fiber amplifier and/or a semiconductor optical amplifier, which bi-directionally generates ASE light of a first band of wavelengths and a second band of wavelengths. The common gain stage 206 supplies Amplified Spontaneous Emission (ASE) light to both output gain stages 205, 207. Both the first output gain stage 205 and the second output gain stages 207 may supply high-powered broadband light in different band of wavelengths or the same band of wavelengths. If the length of the Erbium-doped fiber in the gain stages 205, 207 is approximately the same physical length, then the gain 205, 207 stages may produce the same band of wavelengths. If the semiconductor optical amplifiers are configured to operate in the same band of wavelengths, then the gain stages 205, 207 may produce the same band of wavelengths. A broadband light source using semiconductor optical amplifiers may produce and supply high power light greater than ten milliwatts in power. A broadband light source using rare-earth-element doped optical amplifiers may produce and supply high power light such as 150 - 1000 milliwatts (mW).

[0018] The first output gain stage 205 may include an Erbium-doped fiber amplifier, a semiconductor optical amplifier, or a nonlinear fiber amplifier, which may be configured to amplify broadband light of the first band of wavelengths. The second output gain stage may include an Erbium-doped fiber amplifier, a semiconductor optical amplifier, or a nonlinear fiber amplifier, which use the

broadband light of the first band of wavelengths as a pumping light when generating high power broadband light of a second band of wavelengths.

[0019] Figure 3 illustrates a block diagram of an embodiment of a single broadband light source with a common gain stage simultaneously generating light in a first band of wavelengths and light in a second band of wavelengths.

[0020] The common gain stage 301 may include the following optical components. A first Erbium-doped optical fiber 304. A first optical single-direction pipe 309, such as an optical isolator, connects to the Erbium-doped optical fiber 304 and sends light in the direction of the second gain stage 300. A first wavelength-division-multiplexer 310 connects to the second optical single-direction pipe 311 and the first Erbium-doped optical fiber 304. A first pumping light source 315 connects to a port of the first wavelength-division-multiplexer 310. The second optical single-direction pipe connects to another port of the first wavelength-division-multiplexer 310 and sends light in the direction of the second output port of the third gain stage 302.

[0021] The common gain stage 301 emits C-band ASE. The first pumping light source 315 may use a high power laser diode of 980 nm band or 1480 nm band, fiber laser, etc to supply pump light for the first Erbium-doped optical fiber 304. The first wavelength-division-multiplexer 310 transfers pumping lights to Erbium-doped optical fiber 304. The first Erbium optical fiber 304 bi-directionally generates C-band ASE from the injected pumping light. The optical single-direction pipes 309, 311 may suppress lasing of a particular narrow band of wavelengths in the first band of wavelengths inside the EDFA. The lasing action could be caused by the high internal gain of the EDFA and reflections of the wavelengths in the first band.

[0022] The second gain stage 300 supplies light in the C-band at its output port. The third gain stage 302 supplies light in the L-band at its output port.

[0023] The second gain stage 300 may include the following optical components. A second amplifier such as a second Erbium-doped optical fiber 303, a semiconductor optical amplifier configured to amplify wavelengths within the first band of wavelengths, a fiber amplifier using nonlinear phenomenon such as a Raman amplifier, or similar device to amplify wavelengths within the first band of wavelengths. A second wavelength-division-multiplexer 307 connects to a port of the second Erbium-doped optical fiber 303. A second pumping light source 314

connects to a port of the second wavelength-division-multiplexer 307. A third optical single-direction pipe 306 connects to another port of the second wavelength-division-multiplexer 307 and sends light to the output port of the second gain stage 300. An optical wavelength filter 308 is located between the second Erbium-doped optical fiber 303 and the input port of the second gain stage 300.

[0024] The optical wavelength filter 308 may be a bandpass filter to restrict the optical output of this gain stage to a specific band of wavelengths, a Fabry-Parot filter and an optical interleaver to generate periodic output characteristics, a gain flattening filter to get flat output characteristics, combinations of the listed filters, or similar device.

[0025] The third gain stage 302 may include the following optical components. A third amplifier such as a third Erbium-doped optical fiber 305, semiconductor optical amplifier, a fiber amplifier using nonlinear phenomenon, or similar device to amplify light within the second band of wavelengths. A third wavelength-division-multiplexer 312 connects to the third Erbium-doped optical fiber 305. A third pumping light source 316 connects to a port of the third wavelength-division-multiplexer 312. A fourth optical single-direction pipe 313 connects to another port of the third Erbium-doped optical fiber 305 and sends light to the output port of the third gain stage 302. An input port of the wavelength-division-multiplexer 312 connects to the port from the common gain stage 301. The first output port of the third gain stage may couple to an optical path of a WDM-PON, optical measurement device, or other use of a broadband light source.

[0026] A single optical pump with three output ports may be used for the first pumping light source 316, the second pumping light source 316, and the third pumping light source 316.

[0027] Figure 4 illustrates an example optical power graph for each light signal of the bi-directional ASE generated from an embodiment of the common gain stage. The graph shows an output spectra of the common gain stage having a first ASE light signal 400 transmitted to the second gain stage and a second ASE light signal 401 transmitted to the third gain stage. The first ASE light signal 400 contains the first band and second band of wavelengths. The second ASE light signal 401 contains the first band and second band of wavelengths. In both ASE light signals 400, 401, a peak power is generated at the beginning of the C-band, around 1530

nm, and a relatively strong optical power still exists near the end of the C-band around 1560 nm. A relatively lower optical power is generated throughout the L-band (1570 nm ~ 1600 nm). Most of the ASE light generated in the common gain stage is in the C-band range. The L-band ASE light is lower in optical power since the physical length of the first EDF is relatively short. If the amplifier is a semiconductor optical amplifier the L-band ASE light is lower in optical power since the semiconductor optical amplifier is configured to amplify wavelengths in C-band rather those wavelengths in the L-band.

[0028] Referring to figures 3 and 4, the example first ASE light signal 400 may represent the signal passed out of the first optical single-direction pipe 309. The example second ASE light signal 401 may represent the signal passed out of the second optical single-direction pipe 311. The first optical pump 315, such as a 1480 nm pump laser diode, may supply a pump light to the first Erbium-doped optical fiber 304 having a first physical length such as 9.8 meters (m) to generate the first and second ASE light signals 400, 401. The common gain stage 301 can be used as a C-band broadband light source with two output ports. However, the common gain stage 301 receives aid from the second gain stage 300 to implement a high power C-band broadband light source of 20 dBm (absolute power level measured in decibels) or higher with a flattened output spectrum.

[0029] The second gain stage 300 amplifies the first ASE light signal 400. The optical wavelength filter 308 may be a band-pass filter to limit the amplification of the first ASE light signal 400 to merely the C-band wavelengths in the first ASE light signal 400. A broadband light source of a desired band of wavelengths can be obtained by adjusting the wavelengths passed by the bandpass filter. A broadband light source of a desired band of wavelengths can be also be obtained by adjusting the physical length of the EDF. A high-powered broadband light of desirable strength can be obtained by adjusting the strength of the second pumping light source 314.

[0030] The peak gain coefficient for the broadband light source may be higher than 15 dB/m around 1530 nm. The second and third optical pumps 314 and 316 may also be 1480 nm pump laser diodes.

[0031] The physical length of EDFs 303, 304 and 305 could be length of the common EDF = 6.5 m, length of the second EDF = 7 m, and length of the third EDF

= 57 m, respectively. The pump power of the first, second, and third optical pumps 314, 315, 316 could be as follows: P1 = 170 mW, P2 = 95 mW, and P3 = 160 mW.

[0032] Figure 5 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the second gain stage that contained a gain flattening filter. The optical power spectrum 500 supplied from the output port (306) of the second gain stage may be relatively flat in the C-band (1530 nm -1560 nm). The output optical power may be flattened with the gain flattening filter. The gain-flattening filter may use long-period grating technology. The broadband light source may produce a high power C-band broadband light, whose flattened range is 30 nm within a 1.5 dB spectral variation and whose total output optical power is 20 dBm or higher.

[0033] Figure 6 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the first output gain stage that contains a Fabry-Parot filter and a gain flattening filter. A Fabry-Parot filter with a cycle of N number of GHz could used to match the GHz spacing of the light required by the device receiving the high powered broadband output of the broadband light source. For example, a Fabry-Parot filter with a cycle of 100 GHz could used to match the 100 GHz channel spacing of the International Telecommunication Union (ITU) grid used in optical communications. A Fabry-Parot filter in combination with a gain flattening filter may allow the broadband light source to generate a uniform high power light source with periodic output characteristics. The light within the C-band produced by the first output gain stage may be focused in periodic passbands around the ITU grid wavelengths in the C-band 606. For example, the first periodic band of light 602 and the second periodic band of light 604 may be shaped in their individual wavelengths by the Fabry-Parot filter. The output spectral density at the periodic passbands within the C-band 606 from a Fabry-parot filter and a gain flattening filter can be about 5 dB higher in power level than the uniform band of wavelengths produced with merely a gain flatten filter. Each periodic band may have its individual peak spaced, for example, 100 Ghz apart. The signal power in each periodically spaced peak increases over the uniform signal power because the first output gain stage does not have to use energy to generate ASE in every wavelength in the C-band. The resulting periodic bands can be used for the wavelength-division-multiplexed passive optical network using the

wavelength locked light source if the peak wavelengths match the wavelength allocation of the optical multi/demultiplexer. Also, the periodically spaced broadband output light signal is well suited to measure the characteristics of a fiber amplifier and an optical passive components necessary for wavelength-division-multiplexing since the output light signal shows output characteristics similar to wavelength-division-multiplexed optical signals.

[0034] Figure 7 illustrates an example optical power graph for the optical power spectrum supplied from the output port of an embodiment of the second output gain stage. The graph shows two broadband output signals in the L-band that could be supplied by an output port (313) of the second output gain stage. The first broadband output signal 701 could be an example of the output of the second output gain stage if the common gain stage was not connected and thus, did not supply the C-band ASE pumping light. The first broadband output signal 701 was generated by merely the third EDF being optically pumped by the third optical pump. The second broadband output signal 700 could be an example of the output of the second output gain stage if the common gain stage supplies the C-band ASE pumping light in combination with the pumping light from the third optical pump. The produced output power level of the second band of wavelengths is much different.

[0035] The second broadband output signal 700 may have a flattened level of within +/- 1 dB at a 30 nm or wider area without using a gain flattening filter. The second output gain stage may use an extended length of Erbium-doped optical fiber such as 57 meters to provide the gain and flattening of the output signal. Input light signals from the pumping light sources in the 980 nm or 1480 nm wavelengths may all be absorbed in the initial part of the Erbium-doped optical fiber as the physical length of Erbium-doped optical fiber gets longer. The light in the C-band pumping light wavelengths is transmitted to the inner part of Erbium-doped optical fiber causing this EDF to emit L-band wavelengths. Further, the efficiency of the gain stage can be greatly improved by injecting C-band light from the common gain stage rather than only using C-band pumping light generated directly from within the second output gain stage. The C-band ASE applied received from the common gain stage is amplified in the front part of the EDFA by the 980 nm or 1480 nm pumping light in the second output gain stage. The amplified C-band light from the initial portion of the EDFA is used as a pumping light to generate L-band output ASE from

Erbium-doped optical fiber. The measured total output power from the second output gain stage could be 15.7 dBm with a spectral variation of the output power less than 2 dB. The L-band ASE light may be flattened by optimizing the EDF length. The total power conversion efficiency may be the sum of the L-band power plus the C-band power over the initial pump power and may be about 35 %. This may be an improvement over the power conversion efficiency of a typical single port broadband light source.

[0036] The single broadband light source may be suitable for a low cost wavelength-division-multiplexed passive optical network (WDM-PON), optical measurement devices, or other similar uses. The single broadband light source may be especially suitable to provide seeding light for transmitters at the central office side and seeding light at subscriber side, both use seeding light to wavelength lock to the injected seeding light. Also, the single broadband light source may be especially suitable to measure the spectral characteristics of WDM components.

[0037] Figure 8a illustrates a block diagram of an embodiment of the common gain stage that emits broadband light of a first portion of a first band of wavelengths to the second output gain stage and emits light of a second portion of the first band of wavelengths to the second output gain stage. The common gain stage 807 may provide a high power broadband light source that may include the following components. A bi-directional optical amplifier 807 of a first band of wavelengths with two output ports 803, 804. The bi-directional fiber amplifier 807 may be implemented with an Erbium-doped fiber amplifier, a semiconductor fiber amplifier, or a nonlinear fiber amplifier. The bi-directional fiber amplifier 807 generates ASE light throughout the entire first band of wavelengths such as the C-band (1530 nm to 1560 nm).

[0038] A first port of a first wavelength band separating device 806, such as a wavelength-division-multiplexer, a wavelength selective optical coupler, or similar device, connects to one port of the bi-directional optical amplifier 807. The first wavelength band separating device 806 separates the first band of wavelengths into a first portion of the first band of wavelengths, such as 1530 nm to 1545 nm, and into a second portion of the first band of wavelengths, such as 1545 nm to 1560 nm.

[0039] A first optical reflector 801 may not be dependent on wavelength, such as a mirror. The first optical reflector 801 connects to a second port of the first wavelength band separating device 806. The first optical single direction pipe 805

connects to a third port of the first wavelength band separating device 806. The first wavelength band separating device 806 routes light in the second portion of the first band of wavelengths to the first optical reflector 801. The first wavelength band separating device 806 sends light in the first portion of the first band of wavelengths to the first optical single direction pipe 805. The first optical single direction pipe 805 sends the light in the first portion of wavelengths to the first output port 804.

[0040] Similarly, a first port of a second wavelength band separating device 808 connects to a port of the bi-directional optical amplifier 807. The second wavelength band separating device 808 separates the first band of wavelengths into a first portion of the first band of wavelengths and a second portion of the first band of wavelengths.

[0041] A second optical reflector 809 not dependent on wavelength connects to a second port of the second wavelength band separating device 808. The second optical single direction pipe 802 connects to a third port of the second wavelength band separating device 808. The second wavelength band separating device 808 routes light in the first portion of the first band of wavelengths to the second optical reflector 809. The second wavelength band separating device 808 sends light in the second portion of the first band of wavelengths to the second optical single direction pipe 803. The second optical single direction pipe 802 sends the light in the second portion of wavelengths to the second output port 803.

[0042] The first optical reflector 801 reflects light in the second portion of the first band of wavelengths back through the first wavelength band separating device 806 and is injected again into the bi-directional optical amplifier 807. The amplified second portion of the first band of wavelengths is routed out the second output port 803 through the second wavelength band separating device 808 and the second optical single direction pipe 803. The second output port 803 supplies light in the second portion of the first band of wavelengths to the second output gain stage.

[0043] The second optical reflector 809 reflects light in the first portion of the first band of wavelengths back through the second wavelength band separating device 808 and is injected again injected again into the bi-directional optical amplifier 807. The amplified first portion of the first band of wavelengths is routed out the first output port 804 through the first wavelength band separating device 806 and the first

optical single direction pipe 805. The first output port 804 supplies light in the first portion of the first band of wavelengths to the first output gain stage.

[0044] The first output gain stage amplifies the broadband light in the first portion of the first band of wavelengths to generate high power light in that first portion. The second output gain stage amplifies broadband light in the second portion of the band of wavelengths to generate high power light in that second portion.

[0045] Figure 8b illustrates a block diagram of an embodiment of the common gain stage that emits broadband light of a first portion of a first band of wavelengths to the second output gain stage and emits light of a second portion of the first band of wavelengths to the second output gain stage. The construction and operation is similar to figure 8b except as follows. The common gain stage 800 includes optical reflectors 810, 811 coated with a film to make the reflectors selective in the wavelengths reflected. Also, an optical coupler that is not wavelength selective could also be used instead of the wavelength division multiplexer for devices 814 and 816.

[0046] The first optical reflector 810 reflects the second portion of the first band of wavelengths back into the bi-directional amplifier 807 and prevents any wavelength from the first portion from being reflected back into the bi-directional amplifier 807.

[0047] Similarly, the second optical reflector 811 reflects the first portion of the first band of wavelengths back into the bi-directional amplifier 807 and prevents any wavelength from the second portion from being reflected back into the bi-directional amplifier 807.

[0048] The single multiple band broadband light source based on erbium-doped fiber may generate light at high output power at the various bands of wavelengths. The single multiple band broadband light source may reduce the number of doped-fiber amplifiers and pump lasers needed by multiple light sources having a single output port to provide multiple bands of broadband light. The ASE source may also use optical isolators to suppress potential lasing of a single wavelength within the band of wavelengths caused by the high internal gain and the reflection. The multiple stage configuration based on the EDF technology can improve control of the output power by increasing the pumping power for the output light in a separate gain stage. The broadband light source may be especially useful for the wavelength-

division multiple access passive optical network (WDM-PON) based on the wavelength locked light sources.

[0049] The single broadband light source may provide two or more output ports with a high power broadband light source of the same band of wavelengths or different band of wavelengths. The single broadband light source may simply increase efficiency of generating a broadband light by utilizing all of the bi-directional light generated from the common gain stage. The single broadband light source may provide a precise measurement of optical elements due to the improvement of output optical power.

[0050] The common gain stage bi-directionally generates ASE light in the first band of wavelengths of significant optical power. The broadband light source may contain a fourth gain stage having its own output port. Each different output port supplies a different band of wavelengths.

[0051] Specific numeric references such as first optical reflector, have been made. However, the specific numeric reference should not be interpreted as a literal sequential order but rather interpreted that the first optical reflector is different than a second optical reflector. Likewise, a first band of wavelengths may be 1450 nm to 1500 nm and a second band of wavelengths may be 1310 nm to 1420 nm. Thus, the specific details and implementations set forth are merely exemplary.

[0052] In the forgoing specification, the invention has been described with reference to specific exemplary embodiments thereof. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set fourth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustration rather then a restrictive sense.

CLAIMS

We claim:

1. An apparatus, comprising:

a broadband light source having a common gain stage and two or more output ports, wherein a first output port supplies light in a first band of wavelengths and a second output port supplies light in a second band of wavelengths and the first band of wavelengths is different than the second band of wavelengths.

2. The apparatus of claim 1, wherein the common gain stage contains a bi-directional amplifier that generates amplified spontaneous emission (ASE) light in the first band of wavelengths.

3. The apparatus of claim 1, wherein the first band of wavelengths is the C-band.

4. The apparatus of claim 1, wherein the second band of wavelengths is the L-band.

5. The apparatus of claim 1, further comprising:

a second gain stage that includes

a rare-earth-element doped optical fiber;

the first output port; and

an optical wavelength filter in an optical path between the rare-earth-element doped optical fiber and the common gain stage.

6. The apparatus of claim 5, wherein the optical wavelength filter is a bandpass filter to restrict an optical output of the second gain stage to the first band of wavelengths.

7. The apparatus of claim 5, wherein the optical wavelength filter is a Fabry-Parot filter to generate periodic bands of light within the first band of wavelengths.

8. The apparatus of claim 5, wherein the optical wavelength filter is a gain flattening filter.

9. The apparatus of claim 2, wherein the common gain stage includes an optical single direction pipe connected to the bi-directional amplifier.

10. The apparatus of claim 1, further comprising a third output port, wherein each different output port supplies a different band of wavelengths.

11. The apparatus of claim 1, wherein the broadband light source is capable of producing high power broadband light greater than ten milliwatts in power.

12. The apparatus of claim 1, wherein the first port couples to an optical path of a wavelength-division-multiplexed passive optical network.

13. The apparatus of claim 1, wherein the first port couples to an optical path of an optical measurement device.

14. An apparatus, comprising:

a broadband light source having multiple gain stages including a common gain stage connected to a first output gain stage and a second output gain stage, wherein the common gain stage generates and propagates bi-directionally ASE light having a first band of wavelengths to both the first output gain stage and the second output gain stage, and the second output gain stage generates ASE light in a second band of wavelengths by using the ASE light in the first band of wavelengths as a pumping light.

15. The apparatus of claim 14, wherein the second output gain stage includes an Erbium-doped fiber amplifier.

16. The apparatus of claim 14, wherein the second output gain stage includes a semiconductor optical amplifier and the first output gain stage and second output gain stage supply light in different bands of wavelengths.

17. The apparatus of claim 14, wherein the second output gain stage and the first output gain stage supply light in the same band of wavelengths.

18. The apparatus of claim 14, wherein the second output gain stage includes an Erbium-doped fiber amplifier having a physical length longer than a first Erbium-doped fiber amplifier in the common gain stage and a second Erbium-doped fiber amplifier in the first output gain stage.

19. The apparatus of claim 14, wherein the broadband light source is configured to produce high power light greater than ten milliwatts in power.

20. The apparatus of claim 14, wherein the common gain stage includes

an Erbium-doped optical fiber;

an optical single-direction pipe connected to the Erbium-doped optical fiber;

a wavelength-division-multiplexer connected to the optical single-direction pipe and the Erbium-doped optical fiber; and

a pumping light source connected to the wavelength-division-multiplexer.

21. The apparatus of claim 14, further comprising:

a pumping light source with multiple output ports to supply pump light for the common gain stage, the first output gain stage, and the second output gain stage.

22. The apparatus of claim 14, wherein the common gain stage includes

a semiconductor optical amplifier.

23. The apparatus of claim 14, wherein the common gain stage includes

a non-linear fiber amplifier.

24. An apparatus, comprising:

a broadband light source with a common gain stage, a second gain stage a third gain stage, and two or more output ports.

25. The apparatus of claim 24, wherein a first port of the broadband light source couples to an optical path of a wavelength-division-multiplexed passive optical network.

26. A method, comprising:

simultaneously supplying light in a first band of wavelengths and light in a second band of wavelengths with a single broadband light source having a common gain stage;

amplifying light in the first band of wavelengths received from the common gain stage; and

generating light in the second band of wavelengths by pumping light in the first band of wavelengths received from the common gain stage into a fiber amplifier.

27. The method of claim 26, further comprising:

amplifying the first band of wavelengths in an initial portion of the fiber amplifier; and

transmitting the first band of wavelengths along the fiber amplifier to generate the light in the second band of wavelengths.

28. The method of claim 26, further comprising:

supplying light in the first band of wavelengths by amplifying light in the first band of wavelengths received from the common gain stage.

29. The method of claim 26, further comprising:

filtering light in the first band of wavelengths to provide periodic bands of light within the first band of wavelengths.

30. A system, comprising:

a broadband light source having a common gain stage, a second gain stage, and a third gain stage, wherein the common gain stage has a bi-directional optical amplifier to generate light in a band of wavelengths and emits light of a first portion of the band of wavelengths to the second gain stage and emits light of a second portion of the band of wavelengths to the third gain stage; and

a wavelength-division-multiplexing passive optical network.

31. The apparatus of claim 30, wherein the common gain stage includes

a wavelength band separating device, wherein the wavelength band separating device separates the band of wavelengths into the first portion and the second portion of the band of wavelengths; and

a first optical reflector not dependent on wavelength connected to wavelength band separating device to reflect light in the first portion of the band of wavelengths through the wavelength band separating device into the bi-directional optical amplifier to amplify the first portion of the band of wavelengths.

32. The apparatus of claim 30, wherein the common gain stage includes

an optical coupler connected to the bi-directional optical amplifier; and

an optical reflector being band of wavelengths selective to reflect the first portion of the band of wavelengths through the optical coupler into the bi-directional optical amplifier to amplify the first portion of the first band of wavelengths.

33. An apparatus, comprising:

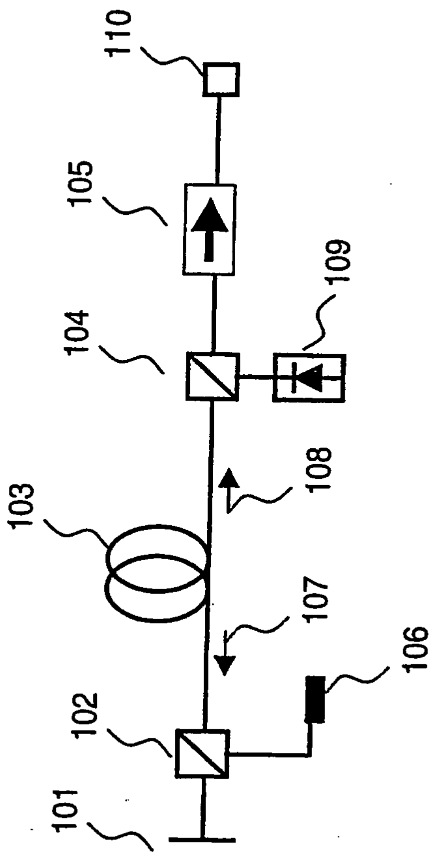
means for simultaneously supplying light in a first band of wavelengths and light in a second band of wavelengths with a single broadband light source having a common gain stage;

means for amplifying light in the first band of wavelengths received from the common gain stage; and

means for generating light in the second band of wavelengths by pumping light in the first band of wavelengths received from the common gain stage into a fiber amplifier.

34. The apparatus of claim 33, further comprising:

means for supplying light in the first band of wavelengths by amplifying light in the first band of wavelengths received from the common gain stage.



Prior Art

Fig. 1

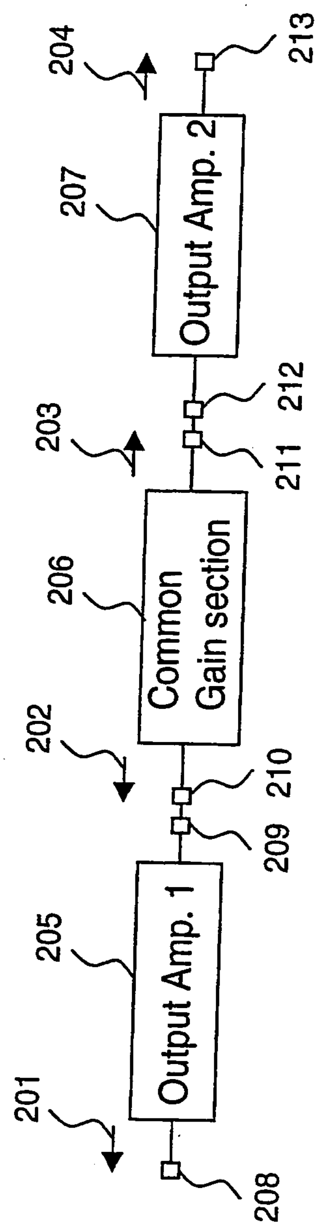

Output Amp. 1
Common Gain section
Output Amp. 2
201
202
203
204
205
206
207
208
209
210
211
212
213

Fig. 2

Fig. 3

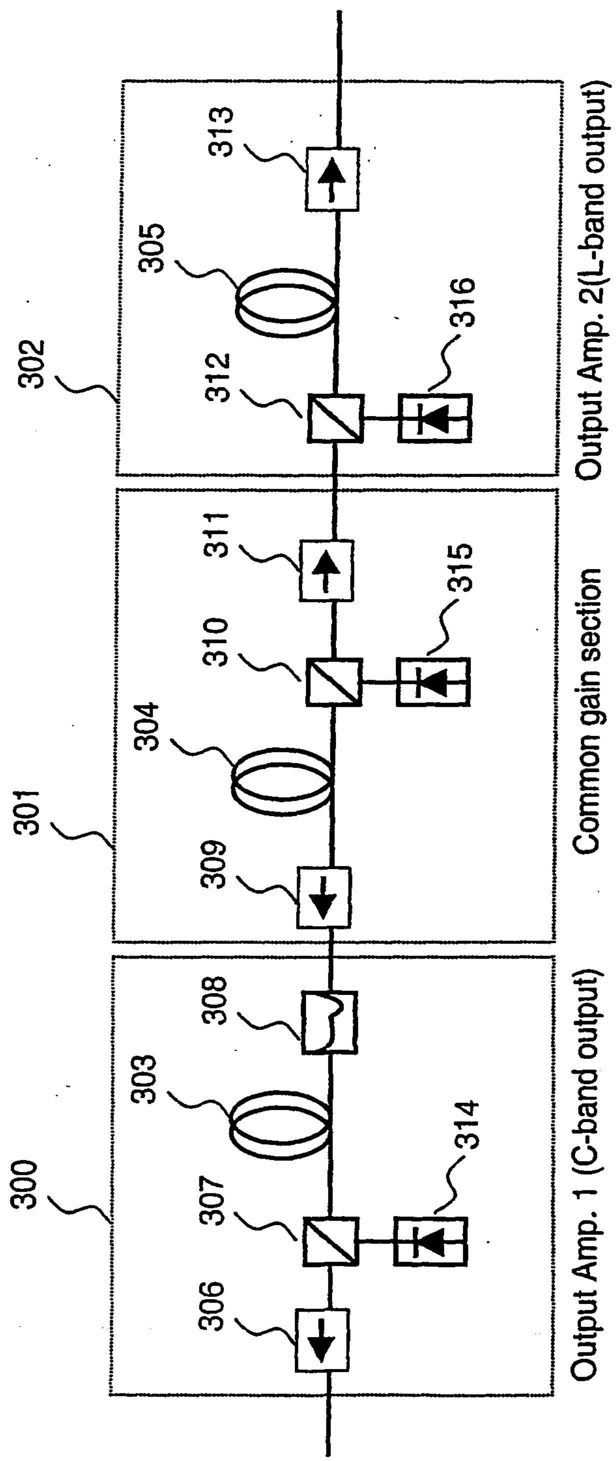

300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
Output Amp. 1 (C-band output)
Common gain section
Output Amp. 2(L-band output)

Fig. 4

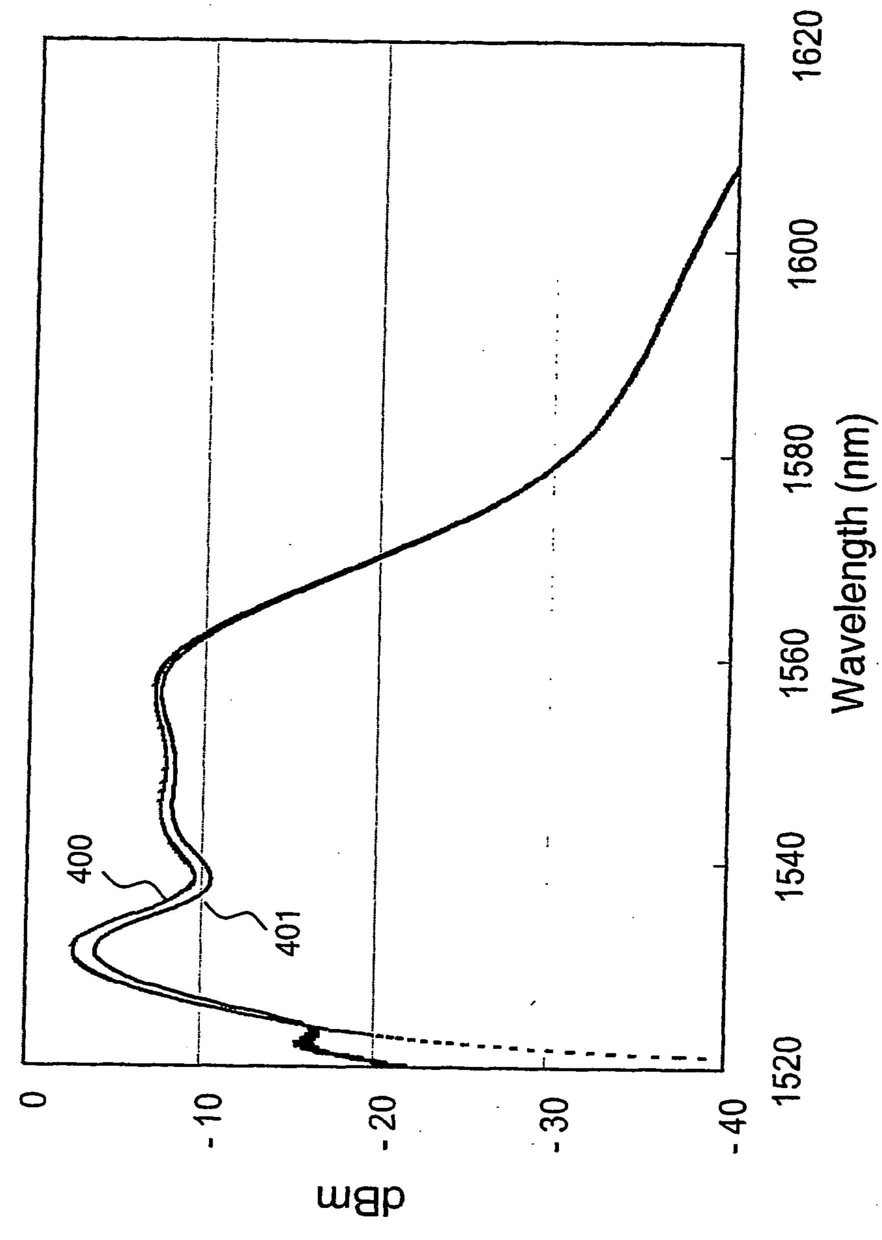

dBm
0
-10
-20
-30
-40
Wavelength (nm)
1520
1540
1560
1580
1600
1620
400
401

Fig. 5

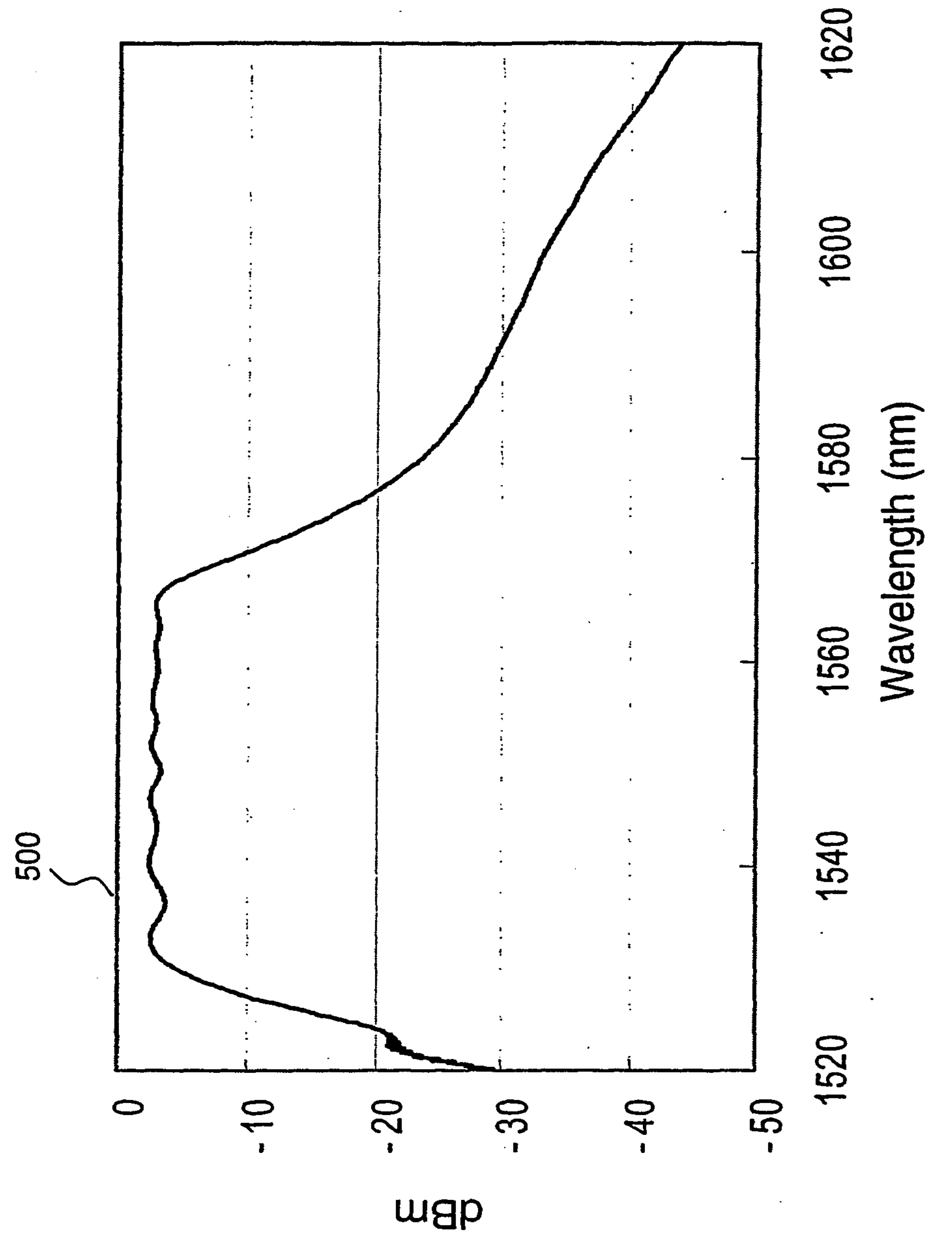

500
0
-10
-20
-30
-40
-50
dBm
1520
1540
1560
1580
1600
1620
Wavelength (nm)

Fig. 6

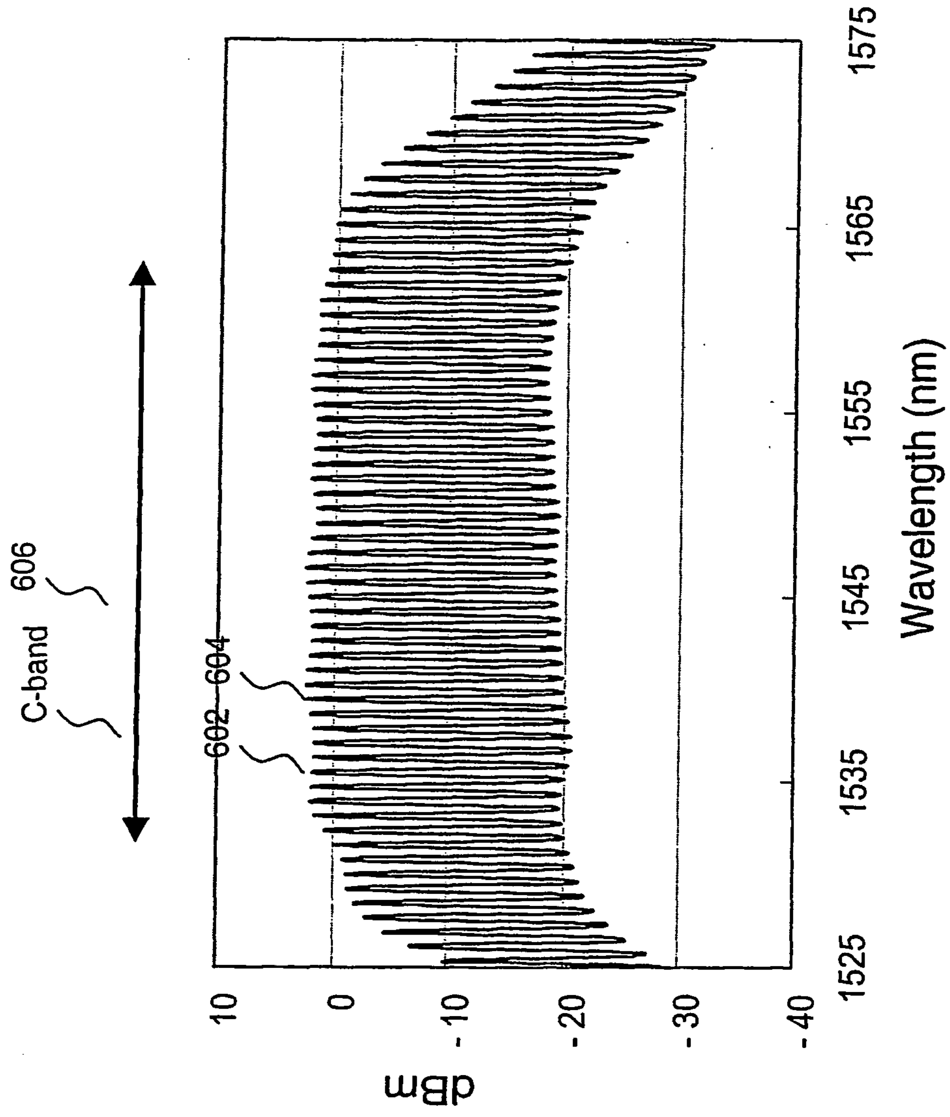
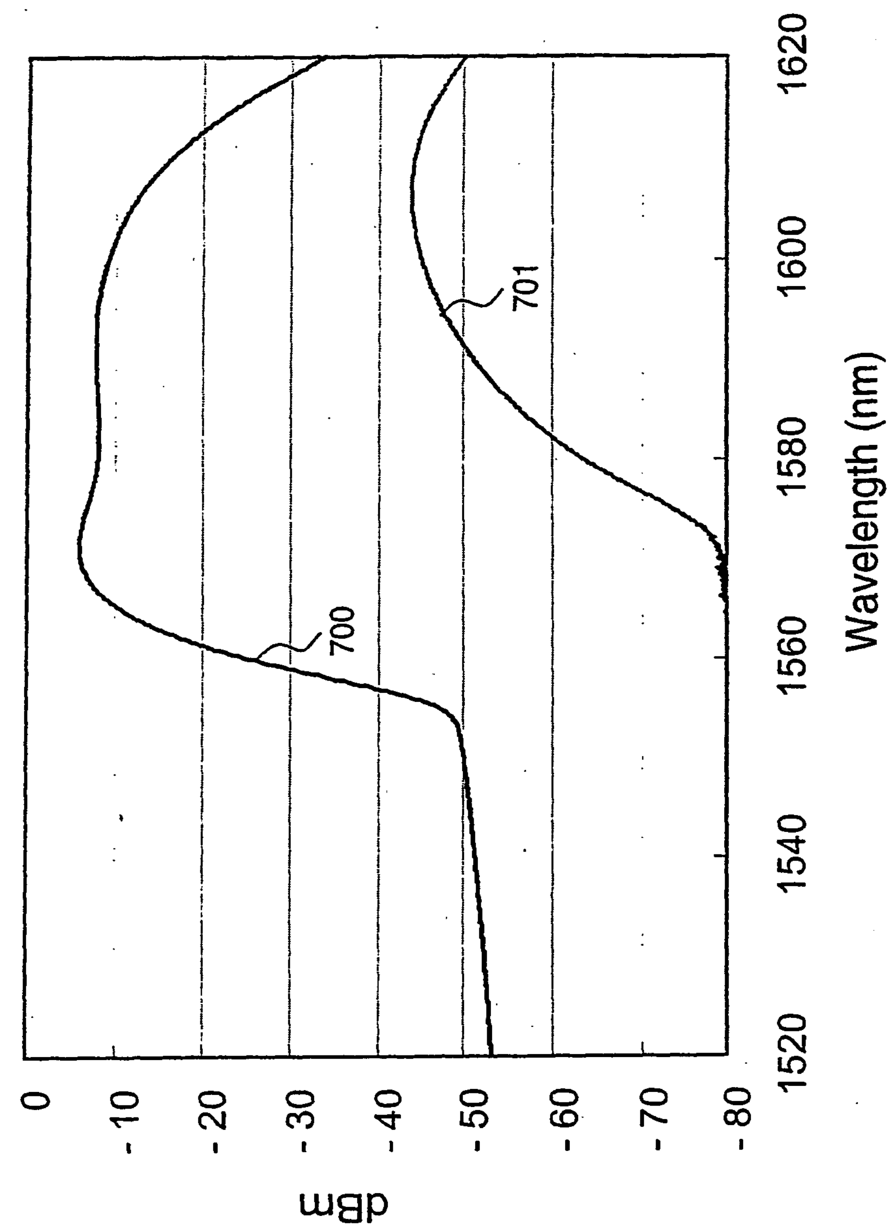

C-band
606
602
604
10
0
-10
-20
-30
-40
dBm
1525
1535
1545
1555
1565
1575
Wavelength (nm)

Fig. 7



dBm
0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
1520
1540
1560
1580
1600
1620
Wavelength (nm)
700
701

Fig. 8 (a)

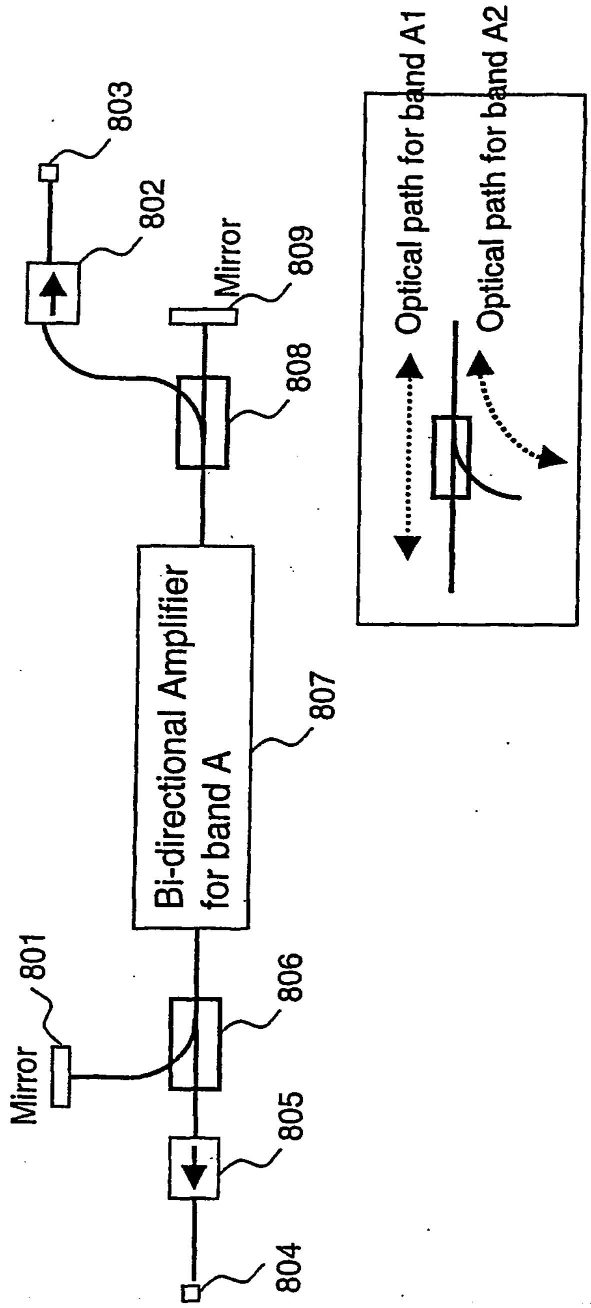
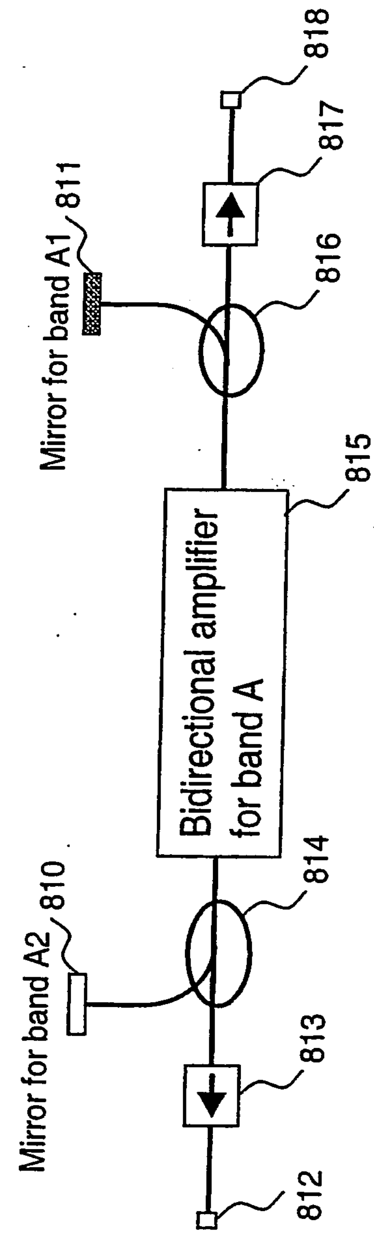

803
802
Mirror
809
808
Bi-directional Amplifier for band A
807
801
Mirror
806
805
804
Optical path for band A1
Optical path for band A2

Fig. 8 (b)


818
817
Mirror for band A1
811
816
815
Bidirectional amplifier for band A
814
Mirror for band A2
810
813
812

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(54) Title: METHODS AND APPARATUSES TO PROVIDE A BROADBAND LIGHT SOURCE WITH TWO OR MORE OUTPUT PORTS

(57) Abstract: Various methods, apparatuses, and systems are described in which a broadband light source supplies multiple sources of light. The broadband light source may have multiple gain stages including a common gain stage connected to a first output gain stage and a second output gain stage. The common gain stage may generate and propagate bi-directionally ASE light having a first band of wavelengths. The common gain stage may supply the ASE light to both the first output gain stage and the second output gain stage. The second output gain stage may generate ASE light in a second band of wavelengths by using the ASE light in the first band of wavelengths as a pumping light.

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International Application No
PCT/US 03/36180

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IPC 7 H04B10/155

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 024 541 A (NIPPON ELECTRIC CO) 2 August 2000 (2000-08-02) column 2, line 15 - column 3, line 25; figures 1,3,5	1-13,24, 25,30
A	US 2001/046364 A1 (AJIMA HIROMI ET AL) 29 November 2001 (2001-11-29) column 1, paragraph 6 - paragraph 7	1-34
A	SAMPSON D D ET AL: "100 mW spectrally-uniform broadband ASE source for spectrum-sliced WDM systems" ELECTRONICS LETTERS, IEE STEVENAGE, GB, vol. 30, no. 19, 15 September 1994 (1994-09-15), pages 1611-1612, XP006001052 ISSN: 0013-5194 the whole document	1-34

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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